

DESCRIPTION

METHOD OF DRIVING AN ELECTROMAGNETIC PUMP

TECHNICAL FIELD

The present invention relates to a method of driving an electromagnetic pump, and in more detail to a method of driving an electromagnetic pump used to convey a fluid such as a gas or a liquid.

BACKGROUND ART

The present applicant has previously proposed a smaller and slimmer electromagnetic pump where a plunger composed of a magnetic material is housed inside a cylinder of a stator so as to be capable of reciprocal movement and a current is passed through a single-phase electromagnetic coil fitted around the cylinder so that in one pump chamber out of the pump chambers formed between both end surfaces of the cylinder and both side surfaces in the direction of movement of the plunger, fluid is introduced from outside via a first valve and fluid is expelled to the outside via a second valve, with the same pumping action being realized in the other pump chamber. By passing a current through the electromagnetic coil, the plunger is caused to move in the axial direction of the cylinder in reaction to the electromagnetic force received by the electromagnetic coil from the magnetic field (see Patent Document 1).

Patent Document 1

Japanese Patent Application No. 2002-286188

As a method of driving the electromagnetic pump described above, there is a method that applies a square wave voltage as shown in FIG. 14 to both ends of the electromagnetic coil to switch the direction of the current flowing in the

electromagnetic coil and drive the plunger. FIG. 14 shows the relationship between the driving voltage and the opening/closing operations of a first intake valve and a first outflow valve and a second intake valve and a second outflow valve provided on the pump chambers. For example, when the square-wave driving voltage on the positive side is applied to the electromagnetic coil, the first intake valve of the pump chamber is opened and then the first outflow valve is closed to introduce fluid into the pump chamber. Also, the second outflow valve is opened and then the second intake valve is closed to expel fluid from the pump chamber. On the other hand, when the square wave voltage on the negative side is applied to the electromagnetic coil, the first outflow valve of the pump chamber is opened and then the first intake valve is closed to expel fluid from the pump chamber. Also, the second intake valve is opened and then the second outflow valve is closed to introduce fluid into the pump chamber.

DISCLOSURE OF THE INVENTION

In the method of driving the electromagnetic pump described above, a current with an approximately square waveform flows in the electromagnetic coil so that the thrust produced for the plunger also has an approximately square waveform. Accordingly, when the polarity of the driving voltage is inverted between positive and negative, the pressure in the pump chamber fluctuates abruptly and the abrupt fluctuation in the forces that act on the inner surfaces of the pump chamber causes the cylinder side surfaces to vibrate. Due to the abrupt fluctuation in the electromagnetic force that acts on the electromagnetic coil on the stator, the stator also vibrates. In addition, when the first intake valve and the second outflow valve or the first outflow valve and the second intake valve are opened, noise and vibration are produced when the valves strongly collide with and come to rest upon engaging surfaces of the frames that form the pump chambers.

In addition, although the first intake/outflow valves and the second

intake/outflow valves are opened and closed due to changes in pressure inside the pump chamber that accompany movement of the plunger, for any of the valves, compared to when the valve is opened from a closed state, the timing at which the valve is closed from an opened state is slightly delayed due to the fluid temporarily flowing in the opposite direction to the preceding direction of flow. At this time, a phenomenon called a “water hammer” occurs where the fluid flowing in the opposite direction collides with the valve to momentarily produce a high-pressure part in the fluid in a narrow flow channel. This water hammer also produces vibration and noise. As one example, a noise level of 33db was detected for the driving method that applies the square wave driving voltage shown in FIG. 14.

The present invention was conceived to solve the problems described above and it is an object of the present invention to provide a method of driving an electromagnetic pump that reduces noise and vibration that accompany abrupt fluctuations in pressure inside a pump chamber when the electromagnetic pump is driven.

To achieve the stated object, a method of driving an electromagnetic pump according to the present invention conveys a fluid from a pump chamber formed inside a cylinder by housing a plunger including a permanent magnet inside the cylinder and passing a current through an aircore electromagnetic coil fitted around the cylinder to reciprocally move the plunger in the axial direction inside the cylinder, wherein a pulse voltage is applied alternately on a positive side and a negative side to drive the electromagnetic coil such that a change in voltage that occurs when the polarity of the pulse voltage is inverted has a continuous slope at least between the positive side and the negative side.

According to another method, the current flowing through the electromagnetic coil is detected and a pulse current flows where a change in current that occurs when the polarity of the current is inverted has a continuous slope at least between the positive side and the negative side.

According to yet another method, a pulse voltage is applied or a pulse current flows including a period where a voltage or current value is zero when the polarity of a driving voltage or a supplied current of the electromagnetic coil is inverted.

According to yet another method, a pulse voltage is applied or a pulse current flows so that an offset voltage of no greater than 30% of a maximum voltage is applied or an offset current of no greater than 30% of a maximum current flows when the polarity of a driving voltage or a supplied current of the electromagnetic coil is inverted.

EFFECT OF THE INVENTION

By using the method of driving an electromagnetic pump described above, a pulse voltage is applied alternately on a positive side and a negative side to drive the electromagnetic coil such that a change in voltage that occurs when the polarity of the pulse voltage is inverted has a continuous slope at least between the positive side and the negative side, or the current flowing through the electromagnetic coil is detected and a supplying of current is controlled so that a pulse current flows where a change in current when the polarity of the current is inverted has a continuous slope at least between a positive side and a negative side, and therefore the excitation direction of the electromagnetic coil is not abruptly inverted. Accordingly, the movement speed of the plunger is eased and abrupt fluctuations in the pressure of the pump chamber are reduced, making it possible to reduce vibration in the cylinder side walls due to abrupt fluctuations in the force that acts on the inner surfaces of the pump chamber. It is also possible to reduce vibration in the stator due to abrupt fluctuations in the electromagnetic force that acts on the electromagnetic coil on the stator. In addition, reverse flow of the fluid when an intake valve or an outflow valve is closed is reduced, thereby easing the water hammer phenomenon and reducing the production of noise and vibration.

Also, by having a pulse voltage applied or a pulse current flow with a period where a value of the voltage or current is zero when the polarity of a driving voltage or a supplied current of the electromagnetic coil is inverted, it is possible to reduce the closing speed of the intake valve or outflow valve for fluid in the pump chamber, reducing reverse flow and easing the water hammer phenomenon, thereby reducing the production of noise and vibration.

Also, by having a pulse voltage applied or a pulse current flow so that an offset voltage of no greater than 30% of a maximum voltage is applied or an offset current of no greater than 30% of a maximum current flows in advance when the polarity of a driving voltage or a supplied current of the electromagnetic coil is inverted, it is possible to reduce the closing speed of the intake valve or outflow valve for fluid on the pump chamber before the maximum voltage is applied or the maximum current flows with the inverted polarity, reducing reverse flow and easing the water hammer phenomenon and thereby reducing the production of noise and vibration. Biasing of the thrust that acts on the plunger in the non-excitation state can be eased by adjusting the offset voltage or offset current so that weak excitation is produced in the opposite direction to the direction of the thrust that acts on the plunger.

Also, by having a minute voltage pulse of at least 30% of a maximum voltage applied or a minute current pulse of at least 30% of a maximum current flow before the period where the value of the voltage or current is zero or the period where the offset voltage is applied or the offset current flows, it is possible to shorten the excitation period for weakening the previous excitation state of the electromagnetic coil, thereby reducing the drop in pump efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a driving voltage waveform diagram for an electromagnetic pump according to a first embodiment.

FIG. 2 is a driving voltage waveform diagram for an electromagnetic

pump according to the first embodiment.

FIG. 3 is a driving voltage waveform diagram for an electromagnetic pump according to the first embodiment.

FIG. 4 is a driving voltage waveform diagram for an electromagnetic pump according to the first embodiment.

FIG. 5 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to a second embodiment.

FIG. 6 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to the second embodiment.

FIG. 7 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to a third embodiment.

FIG. 8 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to the third embodiment.

FIG. 9 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to the third embodiment and timing charts showing the opening and closing of intake valves and outflow valves.

FIG. 10 is a waveform diagram of a driving voltage or supplied current of an electromagnetic pump according to a fourth embodiment.

FIGS. 11A and 11B are diagrams useful in explaining the completely open state of an outflow valve.

FIGS. 12A and 12B are diagrams useful in explaining the completely closed state of an outflow valve.

FIG. 13 is a cross-sectional view showing the overall construction of an electromagnetic pump.

FIG. 14 is a waveform diagram of a driving voltage of a conventional electromagnetic pump and timing charts showing the opening and closing of intake valves and outflow valves.

BEST MODE FOR CARRYING OUT THE INVENTION

Preferred embodiments of a method of driving an electromagnetic pump according to the present invention will now be described together with the construction of the electromagnetic pump with reference to the attached drawings. The electromagnetic pump in the present embodiment can be widely applied to electromagnetic pumps where a plunger including a permanent magnet is housed inside a cylinder and a current is passed through an aircore electromagnetic coil fitted around the cylinder to cause the plunger to move reciprocally in the axial direction inside the cylinder, thereby conveying fluid from a pump chamber formed inside the cylinder.

A representative construction of an electromagnetic pump will now be explained with reference to FIG. 13. A plunger 10 is housed inside a sealed cylinder and is provided so as to be capable of moving reciprocally in the axial direction of the cylinder. The plunger 10 is composed of a magnet 12 formed in a disc-like shape and a pair of inner yokes 14a, 14b that sandwich the magnet 12 in the thickness direction. The magnet 12 is a permanent magnet that is magnetized in the thickness direction (the up-down direction in FIG. 13) thereof with a north pole on one surface and a south pole on the other surface. The inner yokes 14a, 14b are formed of a magnetic material and the inner yokes 14a, 14b respectively include a plate-like portion 15a that is formed with a slightly larger diameter than the magnet 12 and a flange portion 15b that is in the shape of a short tube erected on a circumferential edge portion of the plate-like portion 15a. Outer circumferential surfaces of the flange portions 15b are magnetic flux-acting surfaces of the plunger 10 for the flux produced from the magnet 12.

A sealing member 16 is a non-magnetic member such as plastic that covers an outer circumferential surface of the magnet 12. The sealing member 16 prevents an outer portion of the magnet 12 from being exposed and therefore prevents the magnet 12 from rusting, and also combines the magnet 12 and the inner yokes 14a, 14b into a single body. The sealing member 16 is provided so as to cover the outer circumferential surface of the magnet 12 sandwiched

- between the inner yokes 14a, 14b, but the outer circumferential diameter of the sealing member 16 is formed slightly smaller than the outer circumferential diameters of the inner yokes 14a, 14b.

Next, the construction of the stator of the electromagnetic pump will be described with reference to FIG. 13. A tube-like cylinder is formed by combining a pair of an upper frame 20a and a lower frame 20b composed of a non-magnetic material, with the plunger 10 described above being housed inside the cylinder so as to be capable of reciprocal movement. In the present embodiment, a cylinder portion 24 formed in a tube-like shape is integrally formed with a main body 22b of the lower frame 20b. The end of the cylinder portion 24 engages an engaging groove 28 provided in a main body 22a of the upper frame 20a, resulting in a cylinder with sealed surfaces at both ends in the axial direction being formed by the pair of frames 20a, 20b. A sealing member 29 is provided at a position of the engaging groove 28 contacted by an end surface of the cylinder portion 24 and by pushing the end surface of the cylinder portion 24 against the sealing member 29, the inside of the cylinder is sealed from the outside. It should be noted that it is also possible to have the cylinder portion 24 extend from the upper frame 20a and engage the lower frame 20b. The cylinder portion 24 may also be formed as a separate component to the upper frame 20a and the lower frame 20b.

In this way, both end surfaces of the cylinder are sealed by the upper frame 20a and the lower frame 20b to form pump chambers 30a, 30b between both end surfaces of the plunger 10 in the direction of movement and the inner wall surfaces of the upper and lower frames 20a and 20b. The pump chambers 30a, 30b correspond to gap parts between both end surfaces of the plunger 10 and respectively the main body 22a of the upper frame 20a and the main body 22b of the lower frame 20b. It should be noted that the plunger 10 slides in contact with the inner surface of the cylinder portion 24 in a state where the gap between the plunger 10 and the cylinder portion 24 is sealed airtight or liquid-tight. To

make the plunger 10 slide favorably, a coating with both a lubricating and a rustproofing effect, such as a fluoride resin coating or a DLC (diamond-like carbon) coating, is applied to the outer circumferential surfaces of the inner yokes 14a, 14b. In addition, a detent that prevents rotation of the plunger 10 in the circumferential direction may also be provided.

Dampers 32 are attached to the end surfaces (inner wall surfaces) of the main bodies 22a, 22b. The dampers 32 are provided to absorb shocks when the inner yokes 14a, 14b strike the end surfaces of the main bodies 22a, 22b. It should be noted that the dampers may be provided not on the end surfaces of the main bodies 22a, 22b but on the end surfaces of the inner yokes 14a, 14b that strike the main bodies 22a, 22b.

A first intake valve 34a and a first outflow valve 36a are provided inside the main body 22a of the upper frame 20a so as to pass through to the pump chamber 30a. A second intake valve 34b and a second outflow valve 36b are provided inside the main body 22b of the lower frame 20b so as to pass through to the pump chamber 30b.

Intake channels 38a, 38b are provided in the upper frame 20a and the lower frame 20b and pass through to the intake valves 34a, 34b. Outflow channels 40a, 40b are also provided in the upper frame 20a and the lower frame 20b and pass through to the outflow valves 36a, 36b. A connecting tube 42 connects the intake channel 38a of the upper frame 20a and the intake channel 38b of the lower frame 20b and a connecting tube 44 connects the outflow channel 40a of the upper frame 20a and the outflow channel 40b of the lower frame 20b. By doing so, the respective intake channels and outflow channels of the upper frame 20a and the lower frame 20b are connected to a single inlet 38 and a single outlet 40.

In FIG. 13, aircore electromagnetic coils 50a, 50b are fitted onto an outer circumference of the cylinder. The electromagnetic coils 50a, 50b are disposed slightly apart in the axial direction of the cylinder and at equal positions with

respect to a center position in the axial direction. The electromagnetic coils 50a, 50b are set so that the lengths in the axial direction are longer than the respective ranges of motion of the flange portions 15b of the inner yokes 14a, 14b. It should be noted that the respective winding directions of the electromagnetic coils 50a, 50b are opposite directions, and by supplying electricity from a single power source, currents are set so as to flow in opposite directions. The reason that the electromagnetic coils 50a, 50b are wound in opposite directions is that the forces that act on the currents flowing in the electromagnetic coils 50a, 50b that are interlinked with the magnetic flux of the magnet 12 are superimposed. These forces act as a reactive force upon the plunger 10 and so produce thrust.

An outer yoke 52 is provided in a tube-like shape and surrounds the outer circumference of the electromagnetic coils 50a, 50b. A magnetic material is used for the outer yoke 52 and increases the amount of magnetic flux interlinked with the electromagnetic coils 50a, 50b so that the electromagnetic force effectively acts on the plunger 10. By providing the flange portions 15b so as to be erected at the edge portions of the inner yokes 14a, 14b that construct the plunger 10, it is possible to reduce the magnetic resistance in the magnetic paths from the inner yokes 14a, 14b to the outer yoke 52 for the flux produced from the magnet 12. By doing so, the total flux amount that acts from the plunger 10 is increased (i.e., magnetic paths are sufficiently achieved), and the magnetic flux generated by the magnet 12 becomes interlinked at right angles to the currents flowing in the electromagnetic coils 50a, 50b with respect to the axial direction, so that thrust can be effectively generated for the plunger 10 in the axial direction. By using this construction, the mass of the plunger 10 is reduced with respect to the generated thrust, and therefore high-speed response becomes possible and the output flow can also be increased.

When the electromagnetic coils 50a, 50b and the outer yoke 52 are assembled with the upper frame 20a and the lower frame 20b, by causing the outer yoke 52 to engage the engaging grooves 28 provided in the upper frame

20a and the lower frame 20b, the outer yoke 52 can be coaxially attached to the cylinder portion 24.

By passing an alternating current through the electromagnetic coils 50a, 50b, the plunger 10 is moved reciprocally (up and down) by the action of the electromagnetic force generated by the electromagnetic coils 50a, 50b. The electromagnetic force generated by the electromagnetic coils 50a, 50b presses the plunger 10 in one direction or another according to the direction of the current flowing through the electromagnetic coils 50a, 50b, and therefore by controlling the current-supplying time and current-supplying direction for the electromagnetic coils 50a, 50b using a control apparatus, not shown, it is possible to reciprocally drive the plunger 10 with an appropriate stroke. When the plunger 10 contacts the inner surfaces of the main bodies 22a, 22b, the shock can be absorbed by the action of the dampers 32.

With the pumping action of the electromagnetic pump according to the present embodiment, the plunger 10 is caused to move reciprocally by the electromagnetic coils 50a, 50b so that fluid is taken into and expelled from the pump chambers 30a, 30b alternately. That is, when the plunger 10 moves downward in the state shown in FIG. 13, fluid is taken into one of the pump chambers 30a and at the same time fluid is expelled from the other pump chamber 30b. Conversely, when the plunger 10 moves upward, fluid is expelled from the pump chamber 30a and at the same time fluid is taken into the other pump chamber 30b. In this way, when the plunger 10 moves to either side, fluid is taken in and expelled, surges in the fluid are suppressed, and fluid can be effectively conveyed.

The electromagnetic pump according to the present embodiment can be used to convey a gas or liquid, with there being no limit on the type of fluid. When the electromagnetic pump is used as a liquid pump, if the conveying pressure of a single plunger 10 is insufficient, a multistage plunger 10 where a plurality of unitary plungers of the same shape respectively composed of a

magnet 12 and inner yokes 14a, 14b are connected may be used. By connecting the unitary plungers in a plurality of stages, it is possible to produce a plunger with large thrust, and therefore an electromagnetic pump with the required conveying pressure can be produced.

Here, one example of an outflow valve 55 that constructs the first and second outflow valves 36a, 36b will be described with reference to FIGS. 11A, 11B and 12A, 12B. FIG. 11 shows an outflow valve 55 in a completely open state while FIG. 12 shows the outflow valve 55 in a completely closed state. The outflow valves 55 open and close the flow channels between the pump chambers 30a, 30b and the first and second outflow channels 40a, 40b. The outflow valve 55 is constructed by integrally connecting a valve body 56 disposed on the first/second outflow channel 40a, 40b side and a stopper 57 disposed on the pump chamber 30a, 30b side via a valve shaft 58. Due to changes in the pressure inside the pump chambers 30a, 30b caused by movement of the plunger 10 described above, the outflow valve 55 is moved in the valve shaft direction. The valve body 56 is formed with a sitting surface (a tapered surface) 60 that can sit and come to rest on a valve seat portion 59 formed in parts of the upper and lower frames 20a, 20b. The stopper 57 is formed in a cross shape and engages an engaging portion 61 formed in parts of the upper and lower frames 20a, 20b.

In a state where the stopper 57 engages the engaging portion 61, the fluid can pass through the valve hole 62 shown in FIG. 11B and flow out from the pump chambers 30a, 30b toward the first and second outflow channels 40a, 40b as shown by the arrows P in FIG. 11A. When the valve body 56 is opened, noise can easily be produced by the stopper 57 strongly striking the engaging portion 61. In FIG. 12A, in a state where the valve body 56 contacts the valve seat portion 59, the flow channels between the pump chambers 30a, 30b and the first and second outflow channels 40a, 40b are closed. At this time, in the flow channels for the fluid, the movement of the valve body 56 causes the fluid to

flow in the reverse direction shown by the arrows Q drawn with broken lines in FIG. 12A, and when the valve is then closed, a water hammer can easily occur where the fluid flowing in the direction of the arrows Q collides with the valve, momentarily producing a high-pressure part in the fluid in a narrow flow channel.

First Embodiment

Next, to overcome the problems that accompany the opening and closing of the valves described above, preferred embodiments of a method of driving an electromagnetic pump will be described with reference to FIGS. 1 to 4. FIGS. 1 to 4 show voltage waveforms applied to both ends of the electromagnetic coils 50a, 50b. It should be noted that the driving voltage (pulse voltage) supplied to the electromagnetic coils 50a, 50b is generated by a driving control circuit, not shown, and as examples, a DC pulse voltage may be generated from a DC power supply voltage or a DC pulse voltage may be generated by rectifying an AC power supply voltage.

FIG. 1 shows the case where a pulse voltage is applied alternately on a positive side and a negative side to drive the electromagnetic coils 50a, 50b such that a change in voltage that occurs when the polarity of the pulse voltage is inverted has a continuous linear slope at least between the positive side and the negative side. FIG. 2 shows the case where a pulse voltage is applied so as to smoothly change to an upper limit value and a lower limit value of the applied voltage according to an exponential function between the positive side and the negative side. By doing so, since the excitation direction of the electromagnetic coils 50a, 50b is not abruptly inverted, the movement speed of the plunger 10 can be eased and abrupt fluctuations in pressure in the pump chambers 30a, 30b can be reduced, so that vibration of the cylinder side surfaces due to abrupt changes in the forces that act on the inner surfaces of the pump chambers can be reduced

and vibration of the stator due to the abrupt fluctuations in the electromagnetic force that acts on the electromagnetic coils 50a, 50b of the stator can be reduced. In addition, reverse flow of the fluid when an intake valve or an outflow valve is closed can be reduced, thereby easing the water hammer phenomenon and reducing the production of noise and vibration. As one example, the noise level is 28dB when the method of driving shown in FIG. 2 is used, which is lower than the conventional art (33dB).

FIG. 3 shows the case where a pulse voltage is applied so that out of the pulse voltage, the slopes are partially reduced for at least parts where the excitation direction switches between the positive side and the negative side, so that the fluctuations in pressure in the pump chambers 30a, 30b at least when the valves open and close are reduced. FIG. 4 shows the case where in addition to using the pulse waveform in FIG. 3, the pulse voltage is applied so that the slopes of the switching parts in the excitation direction linearly differ, so that abrupt fluctuations in the pressure inside the pump chambers 30a, 30b are further eased. By doing so, vibration of the cylinder wall surfaces due to abrupt changes in the forces that act on the inner surfaces of the pump chambers can be reduced, and vibration of the stator due to abrupt fluctuations in the electromagnetic force that acts on the electromagnetic coils 50a, 50b of the stator can be reduced.

Second Embodiment

Next, another example of a method of driving an electromagnetic pump will be described with reference to FIGS. 5 and 6. FIGS. 5 and 6 show voltage waveforms applied to both ends of the electromagnetic coils 50a, 50b or current waveforms that flow in the electromagnetic coils 50a, 50b. FIG. 5 shows the case where a sinewave-shaped pulse voltage is applied to drive the electromagnetic coils 50a, 50b. By applying the sinewave-shaped pulse voltage, the change in voltage is made more gentle when the polarity is inverted, so that the speed of movement of the plunger 10 is eased and abrupt fluctuations in the

pressure inside the pump chambers 30a, 30b can be reduced. By doing so, vibration of the cylinder wall surfaces due to abrupt changes in the forces that act on the inner surfaces of the pump chambers can be reduced, and vibration of the stator due to the abrupt fluctuations in the electromagnetic force that acts on the electromagnetic coils 50a, 50b of the stator can be reduced. As one example, the noise level is 26dB when the method of driving shown in FIG. 5 is used, which is even lower than the method of driving shown in FIG. 2.

FIG. 6 shows the case where a driving voltage $V(t)$ is applied in a range provided by Equation (1) below where the maximum value of the driving voltage $V(t)$ applied to the electromagnetic coils 50a, 50b is set at V_{max} .

$$0.8 \cdot V_{max} \cdot \sin(\omega t) < V(t) < 1.5 \cdot V_{max} \cdot \sin(\omega t) \dots \text{Equation (1)}$$

(where t : time and ω : angular velocity)

In the waveform diagram given in FIG. 6, the broken line A shows $0.8 \cdot V_{max} \cdot \sin(\omega t)$, the broken line B shows $1.0 \cdot V_{max} \cdot \sin(\omega t)$, and the broken line C shows $1.5 \cdot V_{max} \cdot \sin(\omega t)$. The waveform shown by the solid line is the driving voltage waveform. That is, the driving voltage has a waveform that changes continuously in a region surrounded by the broken lines A and C that are sine waves. Since V_{max} is the maximum value of the sine wave voltage, the driving voltage is actually limited to a range of $\pm 1.0 \cdot V_{max}$. In this way, by applying a sinewave-shaped pulse voltage, the change in voltage when the polarity is inverted becomes gentler, the movement speed of the plunger 10 can be eased and abrupt fluctuations in pressure in the pump chambers 30a, 30b can be reduced. Also, by using a voltage waveform where the peak parts of a sinewave are crushed, it is possible to improve the pump output efficiency while suppressing the maximum voltage.

It should be noted that although control of the voltage waveform has been described using FIGS. 5 and 6, it is also possible to carry out control over the supplying of current where the current flowing through the electromagnetic coils 50a, 50b is detected and a pulse current is supplied so that when the polarity

of the current waveform changes, the change in current has a continuous slope at least between the positive and negative sides. It is also possible to carry out control so that a sinewave-shaped pulse current flows to the electromagnetic coils 50a, 50b. In addition, in FIG. 6, current supplying control may be carried out for the supplied current $I(t)$ in a range provided by Equation (2) below where the maximum value of the supplied current $I(t)$ that flows in the electromagnetic coils 50a, 50b is set at I_{max} .

$$0.8 \cdot I_{max} \cdot \sin(\omega t) < I(t) < 1.5 \cdot I_{max} \cdot \sin(\omega t) \dots \text{Equation (2)}$$

(where t : time and ω : angular velocity)

Third Embodiment

Next, another example of a method of driving an electromagnetic pump will be described with reference to FIGS. 7 to 9. FIGS. 7 to 9 show voltage waveforms applied to both ends of the electromagnetic coils 50a, 50b or current waveforms that flow in the electromagnetic coils 50a, 50b.

FIGS. 7 and 8 show the case where a pulse voltage is applied or a pulse current flows so that there is a period where the voltage or current value is zero when the polarity of the driving voltage or the supplied current of the electromagnetic coils 50a, 50b is inverted. FIG. 8 shows the case where current or voltage changes with a linear slope before and after the zero voltage or zero current. By doing so, it is possible to reduce the speed of the valves opening and closing, to reduce the reverse flow, and to ease the water hammer phenomenon, and thereby to reduce the production noise and vibration. As one example, the noise level is 23dB when the method of driving shown in FIG. 7 is used, which is even lower than the method of driving shown in FIG. 5.

FIG. 9 shows the case where a pulse voltage is applied to or a pulse current flows in the electromagnetic coils 50a, 50b so that a minute voltage pulse that is at least 30% of the maximum voltage V_{max} is applied or a minute current pulse that is at least 30% of the maximum current I_{max} flows before the period

where the voltage or current is zero. In FIG. 9, since the minute voltage pulse or current pulse causes excitation in the opposite direction to the preceding voltage or current before the period where the voltage or current value is zero, as one example the first outflow valve and the second intake valve will start to close, so that there is no excitation when the valves completely close. By doing so, it is possible to reduce the non-excitation period, and the drop in pump efficiency can therefore be reduced.

Fourth Embodiment

Next, another example of a method of driving an electromagnetic pump will be described with reference to FIG. 10. FIG. 10 shows a voltage waveform applied to both ends of the electromagnetic coils 50a, 50b or a current waveform that flows in the electromagnetic coils 50a, 50b.

FIG. 10 shows the case where a pulse voltage is applied or a pulse current flows so that when the polarity of the driving voltage or the supplied current of the electromagnetic coils 50a, 50b is inverted, an offset voltage with 30% or less than the maximum voltage is applied or an offset current with 30% or less than the maximum current flows. This offset voltage or offset current causes weak excitation in the opposite direction to the direction of the preceding voltage or current, so that before the maximum voltage V_{max} with the inverse polarity is applied or the maximum current I_{max} with the inverse polarity flows, the speed with which the valves open and close is reduced, the reverse flow is reduced, and the water hammer phenomenon is eased, thereby reducing the production of noise and vibration. Also, the attractive force between the magnet 12 of the plunger 10 and the outer yoke 52 on the stator acts even in the non-excitation state, thereby producing thrust for the plunger 10. The influence of the thrust that acts on the plunger 10 can be eased by weak excitation in the opposite direction to the direction of the thrust that acts on the plunger 10 by adjusting the offset voltage or the offset current.

In FIG. 10, before the period where the offset voltage is applied or the offset current flows, a minute voltage pulse of at least 30% of the maximum voltage may be applied or a minute current pulse of at least 30% of the maximum current may flow (see the dot-dash line in FIG. 10). In this case, aside from easing the influence of the thrust that acts on the plunger 10, it is possible to move the plunger 10 without reducing the speed of movement except at the ends of the range of movement.

It should be noted that although the electromagnetic pump shown in FIG. 1 is an example where the intake channels 38a, 38b provided at both ends of the plunger 10 are connected and the outflow channels 40a, 40b provided at both ends of the plunger 10 are connected, that is, the flow channels are connected in parallel, a plurality of electromagnetic pumps may be used with the flow channels connected in series. In this case, the outflow channel 40a may be connected to the intake channel 38b or the outflow channel 40b may be connected to the intake channel 38a. In addition, although an electromagnetic pump where the respective intake valves 34a, 34b and outflow valves 36a, 36b are provided on the plurality of pump chambers 30a, 30b has been described, the electromagnetic pump may include a pump chamber, an intake valve, and an outflow valve at one position.